

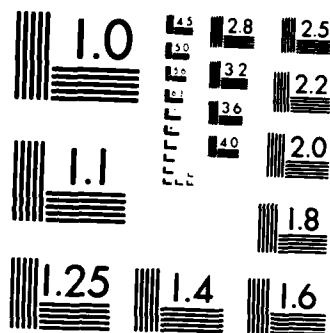
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# OPTICS AND OPTO-ELECTRONIC SYSTEMS

## FINAL REPORT

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OCTOBER 19, 1984

U.S. ARMY RESEARCH OFFICE

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)  Nonlinear Optics in Atomic Vapors Advanced Concepts for Integrated Optics Liquid Lens Devices Pulsed-Energy Statistics in Stimulated Raman Scattering		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number)  ' The work done as a result of this contract had as its objective an understanding of the basic principles that determine the performance of modern optoelectronic systems. The research was carried out by nine faculty members of The Institute of Optics and their students and included topics in integrated optics, non linear optics, image analysis, and electro optical devices. Overall coordination of the program was carried out by the Director of The Institute. The program was organized so as to maximize the involvement of graduate students in the		

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Phase Retrieval by Optical Phase Differentiation  
Nonlinear and Cooperative Effects in Raydberg States  
Computer Processing and Display of Photon-Limited Imagery  
Electrically Pumped Color Center Lasers

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research, recognizing the fact that The Institute of Optics is one of the world's major academic centers specializing in optics. ↗

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## Program Summary

The research program entitled "Optics and Opto-Electronic Systems" was begun on August 1, 1981 at The Institute of Optics with funding from the Army Research Office and later on by the Air Force Office of Scientific Research. The objective of the program was to develop and coordinate a basic research effort devoted to an understanding of the principles which govern the performance of modern opto-electronic systems. To achieve this coordinated approach a multi-investigator program was proposed which involved seven faculty members of The Institute each of whom was responsible for separate but related research projects. Overall coordination of the program was to be carried out by the Director of The Institute to insure the proper allocation of funding, the identification of potential new responsible investigators and access to other major resources of The Institute. The program was also organized so as to maximize the involvement of graduate students in the research effort, recognizing the fact that The Institute of Optics is one of the world's major academic centers specializing in optics. The extent to which the program on Optics and Opto-Electronic systems has achieved these goals is described below.

### Progress Towards Goals and Objectives

One of the strong features of this research program has been its continuity. New research objectives have evolved

and the scope of the work has expanded somewhat, but the faculty involved in the original proposal have maintained their initial effort throughout the three-year period of the contract. The original research projects and responsible investigators were as follows:

1. Generation of Tunable, Coherent Radiation in Atomic Vapors - Robert W. Boyd
2. Scattering in Planar Optical Waveguides - Dennis G. Hall
3. Liquid Lens Devices - Michael C. Lea
4. Non-Linear Optics with Broad-Band Lasers - Michael G. Raymer
5. Cooperative Atomic Radiation at 50 to 1000 Microns - Carlos R. Stroud
6. Electrical Pumping of Color Center Lasers - Kenneth J. Teegarden
7. Methods of Phase Retrieval and Phase Microscopy - Brian J. Thompson

In addition, a new faculty member, Dr. G. Michael Morris, joined the program while it was underway. We feel that the new project he is responsible for, namely, "Computer Processing and Display of Photon-Limited Imagery," markedly strengthens our approach to opto-electronic systems.

#### Research Review

The progress we have made toward the research goals of this program is attested to by the volume and breadth of papers published or submitted for publication and theses completed or in progress. These are listed in Appendix A.



### **Educational Impact**

A substantial number of the graduate students of The Institute have played an important role in the research activities supported under this program. They are listed in Appendix B. Their participation has been an important part of their education and is illustrative of the impact the Program is having on processing manpower needs in the field of optics.

### **Interactions with Other DoD Agencies**

Professor M. Raymer was invited to participate in the High Energy/Power Raman Technology Workshop sponsored by the Night Vision Electro-Optics Laboratory in Ft. Belvoir, Virginia, May 5, 1983. The purpose of the workshop (agenda attached) was to provide a "technical dialogue on Raman laser technology among leading researchers from government, industry, and academic laboratories," and to "review the state-of-the-art Raman technology for military applications." M. Raymer spoke on the quantum statistics of stimulated Raman scattering, reporting work unpublished at the time, concerning fluctuations of the energy of pulses produced by Raman scattering. The workshop was evaluated as "very successful" afterwards, in that a beneficial exchange of information and ideas was accomplished, on both fundamental and applied issues.

Professors Boyd and Teegarden visited the U.S. Army Night Vision and Electro-Optics Laboratory at Fort Belvoir, Virginia in January, 1983. The visit was hosted by Drs.

R. Buser and J. Paul. The object of the visit was to establish areas of mutual interest between The Institute of Optics and NVEOL. The day's events consisted of a series of discussions and tours of the Laboratory. In addition, Professors Boyd and Teegarden presented brief seminars outlining current research interests at The Institute of Optics.

In addition, a cooperative educational program leading to the degree Master of Science in Optics has been developed with the Night Vision and Electro-Optics Laboratory. In this program, students admitted to candidacy for the Master of Science degree by The Institute of Optics may elect to work at NVEOL for eight to twelve months after completing one semester of course work at The Institute. They then finish their program by enrolling for a second semester of courses. The cooperative M.S. program gives both the student and the laboratory a chance to develop an association which may lead to employment after successful completion of the requirements for the degree.

#### Participation by AFOSR

After the initial funding of this program by ARO, the Air Force Office of Scientific Research added additional support for work being carried out by Robert W. Boyd and Carlos R. Stroud specifically for a project entitled "Non-linear and Cooperative Effects in Rydberg States." The total amount committed by AFOSR was \$55,000. We hope to expand participation by the Air Force in the program during the proposed contract period.

## Appendix A

### List of Publications and Manuscripts

1. R.W. Boyd and L.Q. Xiang, "Large d.c.-Electric-Field-Induced Nonlinear Optical Susceptibility of Hydrogenic Atomic Vapors," IEEE J. Quantum Electron. 18, 1242 (1982).
2. R.W. Boyd, L.W. Hillman and C.R. Stroud, Jr., "Natural Modes for the Analysis of Optical Bistability and Laser Notability," Optics Letters 7, 426 (1982).
3. R.W. Boyd and D.J. Harter, "Conical Emission Due to Four-Wave Mixing Enhanced by the ac Stark Effect in Self-Trapped Filaments of Light," Optics Letters 7, 491 (1982).
4. R.W. Boyd, L.W. Hillman, J. Krasinski and C.R. Stroud, Jr., "Homogeneously Broadened Transition," J.O.S.A. 72, 1836 (1982).
5. D.J. Gauthier, J. Krasinski and R.W. Boyd, "Observation of Resonantly Enhanced Sum Frequency Generation Involving Sodium Rydberg States," Optics Letters 8, 211 (1983).
6. L.W. Hillman, R.W. Boyd, J. Krasinski and C.R. Stroud, Jr., "Observation of a Spectral Hole Due to Population Oscillations in a Homogeneously Broadened Optical Absorption Line," Optics Commun. 46, 416 (1983).
7. D.J. Harter and R.W. Boyd, "Four-Wave Mixing Resonantly Enhanced with ac-Stark-Split-Split Levels in Self-Trapped Filaments of Light," Phys. Rev. A 29, 739 (1984).

List of Publications, continued

8. R.W. Boyd, "Spectral Holes Due to Population Oscillations in Homogeneously Broadened Media," in Coherence and Quantum Optics V, ed. by L. Mandel and E. Wolf, (Plenum, New York 1984).
9. R.W. Boyd, D.J. Gauthier and J. Krasinski, "A Novel Technique for Resonantly Enhanced Sum-Frequency Generation Involving Rydberg Atomic States," in Coherence and Quantum Optics V, ed. by L. Mandel and E. Wolf. (Plenum, New York 1984).
10. R.W. Boyd and S. Mukamel, "Origin of Spectral Holes in Pump-Probe Studies of Homogeneously Broadened Lines," accepted for publication in Phys. Rev. A.
11. D.G. Hall, "Scattering of Optical Guided Waves by Waveguide Surface Roughness: A Three-Dimensional Treatment," Optics Letters, 6, 601 (1981).
12. D.G. Hall and E. Bradley, "Out-of-Plane Scattering from Glass Waveguides: Comparison of Theory and Experiment," Optics Letters 7, 235 (1982).
13. G.H. Ames and D.G. Hall, "Attenuation in Planar Optical Waveguides: Comparison of Theory and Experiment," IEEE J. Quantum Electron. QE-19, 845 (1983).
14. W.R. Holland and D.G. Hall, "Surface Plasmon Dispersion Relation: Shifts Induced by the Interaction with Localized Plasma Resonances," Phys. Rev. B27, 7765 (1983).

List of Publications, continued

15. R.W. Gruhlke and D.G. Hall, "Comparison of Two Approaches to the Waveguide Scattering Problem: TM Polarization," Appl. Opt. 23, 127-133 (1984).
16. R.A. Modavis and D.G. Hall, "In-plane Scattering in Planar Optical Waveguides," Opt. Lett. 9, 96-98 (1984).
17. W.R. Holland and D.G. Hall, "Frequency Shifts of an Electric-dipole Resonance Near a Conducting Surface," scheduled to appear in the March 19, 1984, issue of PHYSICAL REVIEW LETTERS.
18. M.C. Lea, "An Optical Modulator Based on Electro-capillarity," Appl. Phys. Lett. 43 (8), 738 (1983).
19. M.C. Lea, "Optical Modulators Based on Electro-capillarity," submitted for publication to Proc. SPIE, 1984.
20. M.C. Lea, "Electrochemical Light Modulators," paper presented at OSA Annual Meeting, New Orleans, October, 1983.
21. G.M. Morris, "Scene Matching Using Photon-Limited Images," to appear in J. Opt. Soc. Am., May, 1984.
22. M.G. Raymer, R. Rzazewski, and J. Mostowski, "Pulse-energy Statistics in Stimulated Raman Scattering," Opt. Lett. 7, 71 (1982).
23. K. Rzazewski, M. Lewenstein, and M.G. Raymer, "Statistics of Stimulated Strokes Pulses Energies in the Steady-State Regime," Opt. Comm. 43, 451 (1982).
24. I.A. Walmsley and M.G. Raymer, "Observation of Macroscopic Quantum Fluctuations in Stimulated Raman Scattering," Phys. Rev. Lett. 50, 962 (1983).

List of Publications, continued

25. M.G. Raymer and I.A. Walmsley, "Quantum Statistics of Stimulated Raman Scattering," to appear in Coherence and Quantum Optics V, Proceedings of the Fifth Rochester Conference held June 13-15, 1983.
26. C.R. Stroud, Jr., D.A. Cardimona, and M.G. Raymer, "Steady-State Quantum Interference in Resonance Fluorescence," Jour. Phys. B, 15, 55-64 (1982).
27. W.A. Molander and C.R. Stroud, Jr., "Altered Branching Ratios and Relaxation Oscillations in Superfluorescent Decays," J. Phys. B, 15, 2109-2114 (1982).
28. K.A. Eagles, C.R. Stroud, Jr., and L. Allen, "The Time Development of Adiabatic Two-Photons Absorption: II Rule Equation Regime," J. Phys. B 15, 2021-2026 (1982).
29. W.A. Molander and C.R. Stroud, Jr., "Quantum vs. Classical Mechanics in the Dynamics of the D.C. Stark Effect," J.O.S.A. 72, 1800 (1982).
30. D.A. Cardimona and C.R. Stroud, Jr., "Spontaneous Radiative Coupling of Atomic Energy Levels," Phys. Rev. A 27, 2456-2461 (1983).
31. K.A. Eagles, C.R. Stroud, Jr. and L. Allen, "The Dynamics of Two-Photon Absorption," in Quantum Electronics and Electro-Optics, ed. by P. Knight (Wiley, N.Y., 1983) p. 121-235.
32. L.W. Hillman, J. Krasinski, J.A. Yeazell and C.R. Stroud, Jr., "Intracavity Power Measurement by Rayleigh Scattering," J. Appl. Opt. 22, 3474 (1983).

### List of Publications, continued

33. L.W. Hillman, R.W. Boyd, J. Krasinski and C.R. Stroud, Jr., "Intrinsic Instabilities in Homogeneously Broadened Lasers," Proceedings of Workshops on Optical Bistability, ed. by C. Bowden and H. Gibbs (Plenum, 1983).
34. M. Malcuit, R.W. Boyd, J. Krasinski and C.R. Stroud, Jr., "Saturation and Inverse Saturation Absorption Lineshapes in Alexandrite," J. Opt. Soc. Amer. B, 1 73 (1984).
35. D.A. Cardimona and C.R. Stroud, Jr., "Photo-excitation to States Laying Very Near the Continuum Limit," to appear in Coherence and Quantum Optics V, ed. L. Mandel and E. Wolf, (Plenum 1984).
36. L. Hillamn, J. Krasinski, R. Boyd and C.R. Stroud, Jr., "Observation of Intrinsic Instabilities in a Homogeneously Broadened Laser," submitted for publication.
37. W.A. Molander and C.R. Stroud, Jr., "Excitation of Circular-Orbit Rydberg States, submitted for publication.
38. R.W. Boyd, L.W. Hillman, M.A. Kramer, J. Krasinski and C.R. Stroud, Jr., "Probe-beam Absorption Line Shapes in Homogeneously Broadened Media," paper presented at OSA Annual Meeting, New Orelans, October, 1983.
39. D.A. Cardimona and J.R. Stroud, Jr., "Near-Unresolved Atomic Excitation," paper presented at OSA Annual Meeting, New Orleans, October, 1983.
40. L.W. Hillman, J. Krasinski, R.W. Boyd and C.R. Stroud, Jr., "Giant Mode Splittings and Hysteresis in a Continuous Wave High-Q Cavity Dye Laser," paper presented at OSA Annual Meeting, New Orleans, October, 1983.

### List of Publications, continued

41. M.S. Malcuit, R.W. Boyd and K.J. Teegarden, "Electrical Pumping of Color Center Lasers," IEEE J. Quantum Electron., 18, 1202 (1982).
42. M.S. Malcuit, R.W. Boyd and K.J. Teegarden, "Electrical Excitation of Laser Radiation in the Alkali Halides," J. Opt. Soc. Am. 72, 1763 (1982).
43. S.R. Wilk, R.W. Boyd and K.J. Teegarden, "Laser Characteristics of  $\text{KCl:O}_2^-$ ," Optics Communications 47, 404 (1983).

### Theses Completed or in Progress

- |                    |   |
|--------------------|---|
| John Bortz         | - "Phase Retrieval by Optical Phase Differentiation"  |
| David A. Cardimona | - "Photoexcitation of Near-Threshold Atomic Energy Levels"  |
| Daniel J. Gauthier | - "Nonlinear Optical Properties of Atomic Rydberg States"   |
| Russell W. Gruhlke | - "Optical Interaction with Coupled Surface Plasmons of Thin Metal Films"                                 |
| Mark Gruneisen     | - "Development of Nonlinear Optical Materials for Phase Conjugation and Image Processing"                 |
| Donald J. Harter   | - "Nondegenerate Four-Wave Mixing Enhanced by the AC Stark Effect"  |
| Lloyd W. Hillman   | - "Interaction of Modulated Optical Fields with Saturable Media and its Application to Laser Instability" |



Thesis Completed or in Progress,

continued

- |                     |   |  |
|---------------------|---|--|
| William R. Holland  | - | "Optical Plasma Resonances of<br>Metal Films                           |
| Mark Kramer         | - | "Nonlinear Optical Properties of<br>Impurity Doped Solids"             |
| Michelle Malcuit    | - | "Electrical Pumping of Color Center<br>Lasers"                         |
| William A. Molander | - | "Transitions Between Highly Excited<br>States of Alkali Atoms"         |
| Ian Walmsley        | - | "The Quantum Statistics of Many<br>Photon Stimulated Raman Scattering" |
| Stephen R. Wilk     | - | "A $\text{KCl:O}_2^-$ Laser"   |

## Appendix B

### Students Supported by Program

- + John Bortz (Ph.D.)
- + David Cardimona (Ph.D.)
- + Jeffrey Doyle (M.S.)
  - Daniel Gauthier (Ph.D.)
  - Tom Glass (M.S.)
  - Michael Greenberg (M.S.)
  - Russell Gruhlke (Ph.D.)
  - Mark Gruneisen (Ph.D.)
- + Donald Harter (Ph.D.)
- + Lloyd Hillman (Ph.D.)
  - William Holland (Ph.D.)
  - Karl Koch (Ph.D.)
  - Bruce Krakauer (Ph.D.)
  - Mark Kramer (Ph.D.)
  - Michelle Malcuit (Ph.D.)
  - Richard Manning (M.S.)
  - William Molander (Ph.D.)
  - Mark Skeldon (Ph.D.)
  - Iam Walmsley (Ph.D.)
- + Stephen Wilk (M.S.)
  - John Yeazell (Ph.D.)

+ Degrees Completed

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